Name **Date**

HANDS-ON LAB
Measuring Acceleration

When Galileo Galilei and Sir Isaac Newton were investigating motion, digital cameras, smartphones, and electric timers did not exist. These scientists observed motion with the unassisted eye, and they used simple clocks to measure time. Facing the challenge of obtaining accurate measurements, these scientists examined how they could evaluate the horizontal and vertical components of motion independently.

Suppose you are studying the movement of a ball across a table but you do not have sophisticated equipment to measure motion. Evaluate what you know about motion that might help you develop an effective procedure for the investigation. For example, the force that pulls an object down a ramp is the same force that pulls a projectile down to the ground. Horizontal motion through the air follows the same quantitative patterns as motion along the ground.

MATERIALS
- safety goggles
- balls, identical, that can hit the floor without damage (2)
- desk or table
- flat surface that can be used to make a ramp, such as a binder
- meterstick

In this lab, you will use mathematical relationships that describe the horizontal motion and vertical motion to find the acceleration of a ball rolling down a ramp.

RESEARCH QUESTION How can you use projectile motion to measure an object's acceleration down a ramp?

MAKE A CLAIM
If one ball falls straight down and another ball flies out as a projectile from the same height, will they land at the same time? Explain your answer.

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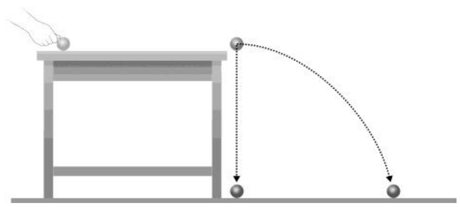
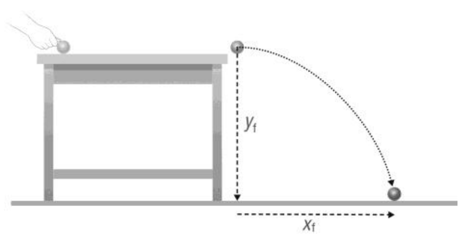
SAFETY INFORMATION
- Wear safety goggles during the setup, hands-on, and takedown segments of the activity.
- Immediately pick up any items dropped on the floor so they do not become a slip/fall hazard.
- Wash your hands with soap and water immediately after completing this activity.

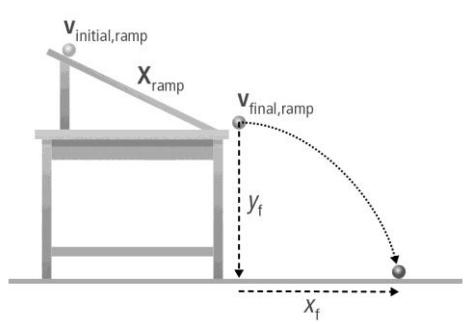
A ball rolls off a level table. The path followed by the projectile is defined by y_f and x_f. In **Figure c**, the ball is launched using a ramp, making it easy to reproduce the same horizontal velocity in each trial.



a Trial run 1



b Trial run 2



c Trial run 3 $\mathbf{x}_{ramp}$

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CARRY OUT THE INVESTIGATION

Part 1: Calculate Horizontal Velocity

Trial 1: Roll a ball off the edge of a table. The instant the rolling ball leaves the table, drop a second ball from the same height. Do the two balls land at the same time? Is the result what you expect after studying parabolic motion?

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Trial 2: Vary the speed at which you roll the first ball off the table. Observe what happens. For one trial, measure the horizontal distance from the table edge to where the launched ball lands, x_f. Measure the vertical distance both balls fall, y_f. You will use these values to calculate the time the ball takes to fall and the initial horizontal velocity when the launched ball leaves the table.

The initial vertical velocity for both balls is 0 m/s because the first ball is moving only horizontally and the second ball is at rest. Use Steps a and b below to calculate the initial horizontal velocity for the launched ball.

a. Use your value for y_f and the equation $y_f = \left(\frac{1}{2}\right)(9.8\ \text{m/s}^2)t^2$ to find *t*, the time the ball took to fall.

b. Use this value for *t* and the value you measured for x_f to solve $x_f = x_i + \mathbf{v}_x t$ for $\mathbf{v}_x$. (Note that $x_i = 0$ m.)

Record your measurements and calculations in a data table that you construct in your Evidence Notebook. A sample grid is provided below.

Data for Trial 2 $y_f =$ _________

Trial	x_f — dropped (m)	x_f — launched (m)	t — dropped (s)	t — launched (s)	$\mathbf{v}_x$ (m/s)

Part 2. Calculate the Acceleration of a Ball on a Ramp

Trial 3: Roll the first ball down a ramp that is set back from the edge of the table by a short distance. The ball should be moving horizontally when it gets to the edge of the table and falls off. Use Steps c–g to calculate the acceleration of the ball (**a**)**:**

c. Measure the length of the ramp, **x**, and substitute your value into the equation for accelerated motion, $\mathbf{x} = \mathbf{x}_i + \mathbf{v}_i t + \left(\frac{1}{2}\right)\mathbf{a}t^2$. This equation reduces to $\mathbf{x} = \left(\frac{1}{2}\right)\mathbf{a}t^2$ because $\mathbf{x}_i = 0$ m and $\mathbf{v}_i = 0$ m/s. The values of **a** and *t* are still unknown.

d. Substitute $\left(\frac{\Delta \mathbf{v}}{t}\right)$ for **a**:

$$\mathbf{x} = \left(\frac{1}{2}\right)\mathbf{a}t_{\text{ramp}}{}^2$$

$$\mathbf{x} = \left(\frac{1}{2}\right)\left(\frac{\Delta \mathbf{v}}{t_{\text{ramp}}}\right)t_{\text{ramp}}{}^2$$

$$\mathbf{x} = \left(\frac{1}{2}\right)\Delta \mathbf{v} t_{\text{ramp}}$$

e. Use the method from Trial 2 to calculate $\Delta \mathbf{v}$ for the ramp. Recall that $\Delta \mathbf{v} = \mathbf{v}_{\text{final}} - \mathbf{v}_{\text{initial}}$. Because $\mathbf{v}_{\text{initial}} = 0$ m/s, $\Delta \mathbf{v} = \mathbf{v}_{\text{final}}$. The horizontal velocity $(\mathbf{v}_x)$ for the launched ball is also the ball's final velocity $(\mathbf{v}_{\text{final}})$ when it reaches the bottom of the ramp. So, $\Delta \mathbf{v} = \mathbf{v}_{\text{final}} = \mathbf{v}_x$.

f. Substitute your values for **x** and $\Delta \mathbf{v}$ to solve for t.

g. Then solve $\mathbf{a} = \left(\frac{\Delta \mathbf{v}}{t_{\text{ramp}}}\right)$ for **a**.

Record your measurements and calculations in a data table that you construct in your Evidence Notebook. A sample grid is provided below.

Data for Trial 3 y_f = __________

Trial	Setting	x (m)	x_f (m)	t (s)	v_x (m/s)	t_{ramp} (s)	a (m/s^2)	Notes

ANALYZE

1. What evidence do you have that motion can be separated into horizontal and vertical motion?

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2. How does the horizontal speed of the ball rolling across the table correspond to x_f?

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3. How does the change in velocity caused by the ramp correspond to the ramp's length?

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CONSTRUCT AN EXPLANATION

Why can you use the projectile-motion method to determine the acceleration of the ball down the ramp? Explain the reasoning steps involved in your calculations for Trial 3.

DRAW CONCLUSIONS

Write a conclusion that addresses each of the points below.

Claim If one ball falls straight down and one flies out as a projectile from the same height, will they land at the same time? Explain if your results confirm or refute your initial predictions.

Evidence What evidence from your investigation supports your claim?

Reasoning Explain how the evidence you gave supports your claim. Describe in detail the connections between the evidence you cited and the argument you are making.

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EXTEND

1. Suppose the ball is launched off a table by a hand giving it a steady push over a certain distance. How would you calculate the average acceleration of that push?

2. What are some other methods and equipment that could be used to measure the acceleration of an object? What are the possible advantages of the other methods?